International Journal of Industrial Engineering, 16(4), 344-352, 2009.

FINGER DISABILITIES AND HIGHER LEVEL TASKS – DEVELOPING AND VALIDATING MTM MULTIPLIERS

Anand Subramanian[1] and Anil Mital[2]

[1]Managing Engineer
JFAssociates, Inc.
Fairfax, VA 22031

[2]Mechanical Engineering Department
University of Cincinnati
Cincinnati, OH 45221-0072, USA

MTM multipliers are developed for higher level tasks such as manual lifting, lowering, carrying and assembly with hands, as well as manual tools. These MTM multipliers and those developed in the previous work were applied to estimate the cycle time of individuals with finger disabilities for a combination assembly and handling task. Once the cycle time was estimated, the actual task was performed and the performance cycle time was determined from video analysis. The estimated and observed cycle times were compared. Additionally, estimated and observed elemental times were compared. The results of statistical comparison indicated that the difference between the estimated and actual cycle times was insignificant ($\alpha \geq 0.10$). Further, elemental times based on observation were not significantly different from those estimated from multipliers established in the earlier work and the work presented here.

Significance: MTM PMTS multipliers are provided for complex higher level tasks performed by individuals with finger disabilities. These multipliers were validated.

Keywords: Finger disability, manual materials handling, MTM, PMTS.

(Received 27 June 2007; Accepted in revised form 26 June 2009)

1. INTRODUCTION

Previous work (Subramanian and Mital, 2009) demonstrated that individuals with finger disabilities require a substantially longer time to perform simple assembly and disassembly tasks. The increase in time could be as much as one hundred fifty percent more than what individuals without disability take. On the basis of these results, MTM multipliers were developed for basic elements such as grasp and position. It was discussed that realistic tasks are higher-order tasks that require more complex manipulation and it is necessary to develop multipliers for those tasks. Keeping that in mind, the purpose of this study was: (1) to develop modifiers for higher level tasks (manual lifting, manual carrying, manual lowering, loading, unloading, assembly using only hands, and assembly using hands and manual tools) and (2) to validate these multipliers. In order to be consistent with the previous study, the same finger disabilities were simulated. These disabilities were: (1) the loss of four fingers in the primary (preferred) hand (condition-D01); (2) the loss of the thumb in the non-preferred hand (condition-D02); and (3) the loss of four fingers in the primary (preferred) hand and the loss of thumb in the non-preferred hand (condition-D03). As in the previous work, the no disability condition was the control condition.

Two higher level tasks were studied. The first task was an assembly-disassembly task and was performed using only hands and subsequently hands and manual tools (wrenches and screw drivers). The second task was a complex combination task that included various materials handling elements.

The multipliers generated from the two studies and those from previous works were subsequently validated in a third study. This next study simulated a combination that included aspects of both assembly and materials handling, thus allowing verification of both simple MTM multipliers as well as multipliers for higher level tasks.

Subsequent sections of the paper discuss the three studies and the results obtained.

2. HIGHER LEVEL TASK MULTIPLIERS

As stated above, two separate studies were carried out to generate higher level multipliers to estimate time for individuals with finger disabilities. These studies are described below.

2.1 Assembly/Disassembly task with hands and manual tools

2.1.1 The Experiment and Data Analysis

The experimental setup and the disability conditions were identical to the one used in the previous study (Subramanian and Mital, 2009). Yet, instead of performing simple assembly and disassembly, the twenty participants assembled different sizes of bolts and then disassembled them without stopping. The order of bolt size was left up to the participant. The task is outlined in Table 1. The starting and ending point for each activity are given in Table 2. All four simulated disability conditions were performed in a random order and the performance was videotaped.

Table 1. List of High Level Tasks

Assembly	Disassembly
Large bolt assembly	Large bolt disassembly
Assemble LNB-hands	Disassemble LNB-tools
Assemble LNB-tools	Disassemble LNB-hands
Medium bolt assembly	Large bolt disassembly
Assemble MNB-hands	Disassemble LNB-tools
Assemble MNB-tools	Disassemble LNB-hands
Small bolt assembly	Large bolt disassembly
Assemble SNB-hands	Disassemble LNB-tools
Assemble SNB-tools	Disassemble LNB-hands

Table 2. Descriptions of start and end points for High level tasks

Activity	Start Point	End Point
Assembly (Large, Medium, Small)	First limb movement to reach for first item (nut, bolt, or washer)	Last touch or release of the tools after completing the assembly operation
Disassembly (Large, Medium, Small)	First limb movement to reach for the tools	Last touch or release of the nuts, bolts, or washer after completing the disassembly operation
Assemble NB-hands (L,M,S)	Subject starts to assemble the washer-nut to the bolt or end of the position NB activity (if no delays are present)	Subjects begins to move limbs to reach for the tools after tightening the nut-bolt with hands
Assemble NB-tools (L,M,S)	Limbs reach the location of assembly or limbs stop moving	Limbs move away from the assembly after tightening
Disassemble NB-tools (L,M,S)	Limbs reach the location of assembly or limbs stop moving	Limbs move away from the assembly after loosening the nut-bolt assembly
Disassemble NB-hands (L,M,S)	Limbs reach the location of assembly or limbs stop moving	Limbs move away from the wooden uprights after completely dismantling the nut-bolt assembly

2.1.2 Results

The video time data for each of the three disability conditions – performance with the three simulated finger disabilities – was compared with the video time data for the control condition. The comparison was made for each higher task element. This comparison is shown in Table 3.

Table 3. Percentage variation for each disability over the control scenario

Task	D01	D02	D03
Large Bolt	11.33%	7.27%	44.35%
Assemble LNB-hands	13.40%	6.24%	51.47%
Assemble LNB-tools	7.67%	9.00%	57.07%
Medium Bolt	9.26%	8.52%	42.30%
Assemble MNB-hands	8.65%	9.82%	50.39%
Assemble MNB-tools	14.13%	8.48%	57.87%
Small Bolt	29.94%	15.84%	82.55%
Assemble SNB-hands	39.53%	15.24%	91.65%

Task	D01	D02	D03
Assemble SNB-tools	32.17%	15.42%	108.03%
Large Bolt Disassembly	11.34%	4.23%	25.08%
Disassemble LNB-tools	20.50%	4.52%	29.42%
Disassemble LNB-hands	6.23%	4.80%	27.28%
Medium Bolt Disassembly	6.04%	4.04%	49.12%
Disassemble MNB-tools	5.18%	4.87%	54.49%
Disassemble MNB-hands	7.82%	3.82%	57.70%
Small Bolt Disassembly	26.97%	18.80%	63.00%
Disassemble SNB-tools	33.19%	22.19%	73.10%
Disassemble SNB-hands	30.37%	21.77%	74.10%

For each task standard MTM-2 times were estimated. These estimates were then compared to the respective observed time data for each disability condition. The comparison provided the appropriate multiplier. These multipliers are given in Table 4.

Table 4. Correction factors for finger disability conditions

Activity	D01	D02	D03
Large Bolt	1.11	1.07	1.44
Assemble LNB-hands	1.13	1.06	1.51
Assemble LNB-tools	1.08	1.09	1.57
Medium Bolt	1.09	1.09	1.42
Assemble MNB-hands	1.09	1.10	1.50
Assemble MNB-tools	1.14	1.08	1.58
Small Bolt	1.30	1.16	1.83
Assemble SNB-hands	1.40	1.15	1.92
Assemble SNB-tools	1.32	1.15	2.08
Large Bolt Disassembly	1.11	1.04	1.25
Disassemble LNB-tools	1.20	1.05	1.29
Disassemble LNB-hands	1.06	1.05	1.27
Medium Bolt Disassembly	1.06	1.04	1.49
Disassemble MNB-tools	1.05	1.05	1.54
Disassemble MNB-hands	1.08	1.04	1.58
Small Bolt Disassembly	1.27	1.19	1.63
Disassemble SNB-tools	1.33	1.22	1.73
Disassemble SNB-hands	1.30	1.22	1.74

2.2 Manual Handling tasks

Figure 1. Manual Handling Equipment

2.2.1 The Task

The task simulated is a task that is routinely performed in the food service and restaurant industry. The equipment, shown in Figure 1, consisted of a set of ten plates and seven glasses in a special washing basket. The task sequence performed is shown in Figure 2. Figure 3 shows the schematic layout of the task setup.

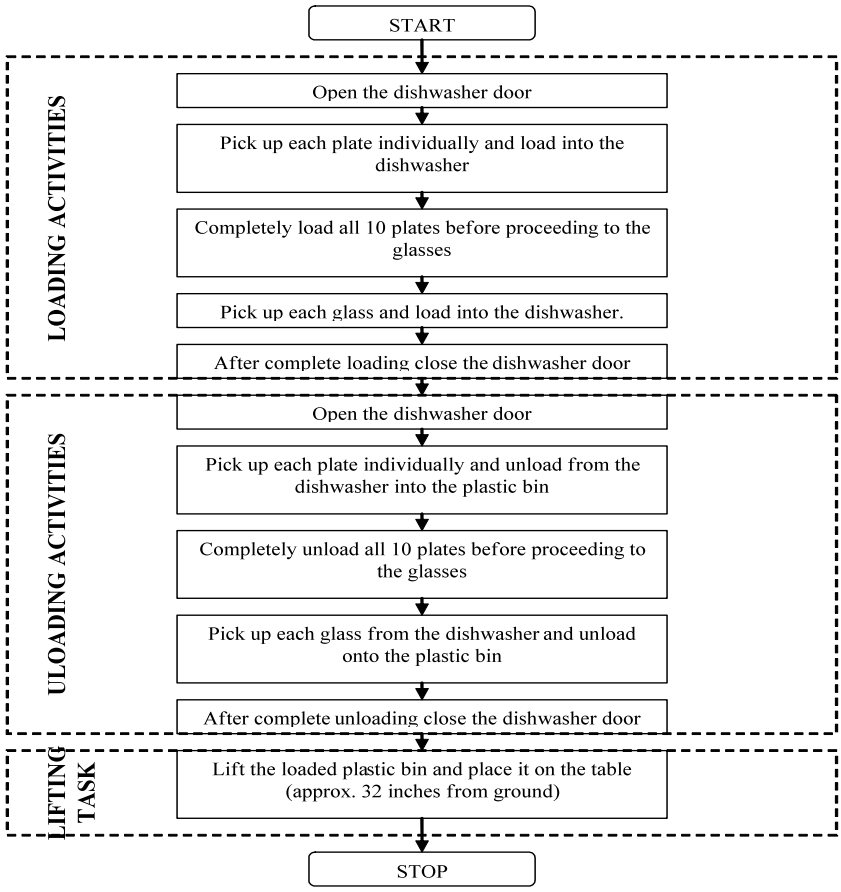

Figure 2. **Typical sequence of operations for manual handling tasks**

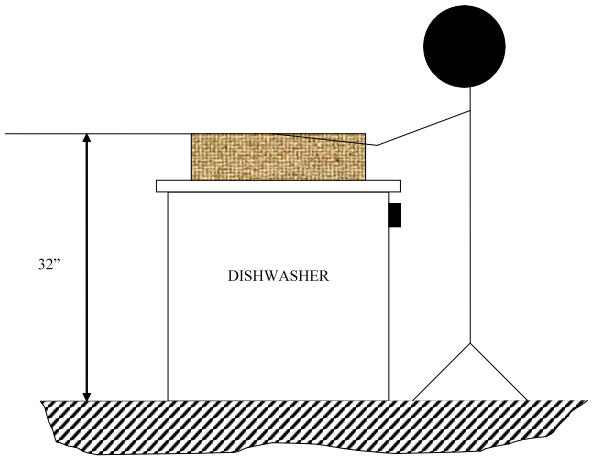

Figure 3. The setup used for the loading/unloading/lifting tasks

As in the case of the assembly-disassembly task, each participant performed this task in a random order of the three finger disabilities and the control condition.

2.2.2 Data Analysis

Table 5 shows the list of manual handling tasks that were timed in the high level task analysis. The procedure of video analysis was the same as in the previous task. The precise start and end points for each of the element timed are listed in Table 6.

Table 5. List of elements timed

Materials Handling Tasks
Loading
Unloading
Lifting

Table 6. Descriptions of start and end points for Materials Handling Tasks

Task	Start Point	End Point
Loading	Limbs start moving towards the location of plates or for opening the dishwasher door (whichever occurs first)	Limbs start retracting away from the dishwasher door after completely loading plates and glasses.
Unloading	Limbs start moving towards the location of plates or for opening the dishwasher door (whichever occurs first)	Limbs start retracting away from the dishwasher door after completely unloading plates and glasses.
Lifting	Limbs start moving towards the plastic bins or end of unloading activity (if no delays are present)	Limbs start retracting away from the plastic bin after placing it on the work surface

2.2.3 Results

The elemental times for each experimental condition – performance with the three simulated finger disabilities– were compared with the respective elemental time of the control condition. This comparison is shown in Table 7.

Table 7. Percentage variation for each disability over the control scenario

Task	D01	D02	D03
Loading	3.09%	0.85%	9.84%
Unloading	4.45%	2.12%	8.66%
Lifting	29.37%	13.99%	139.07%

As shown in Table 7, most elemental times for the disability conditions took significantly longer to perform than the control condition ($\alpha < 0.05$).

For each task, standard MTM times were determined. These times were then compared to the video time data for each respective disability condition to arrive at appropriate multiplier (correction factor). These multipliers are given in Table 8.

Table 8. Multipliers for finger disability conditions for Materials Handling Task

Task	D01	D02	D03
Loading	1.03	1.01	1.10
Unloading	1.04	1.02	1.09
Lifting	1.29	1.14	2.39

3. VALIDATION STUDY

A verification study was conducted to test the applicability of the different multipliers developed in the previous work (Subramanian and Mital, 2009) as well as in the two studies described here in the previous sections (MTM-2 and materials handling task multipliers). As before, the three finger disabilities were simulated. The procedure was to estimate elemental times using the developed multipliers and the cycle time for the tasks and then compare them to the observed time to perform the same tasks. The same procedure was used to collect the data and analyze the data as described previously (Subramanian and Mital, 2009). Figure 4 shows the sequence of activities that was used for the study.

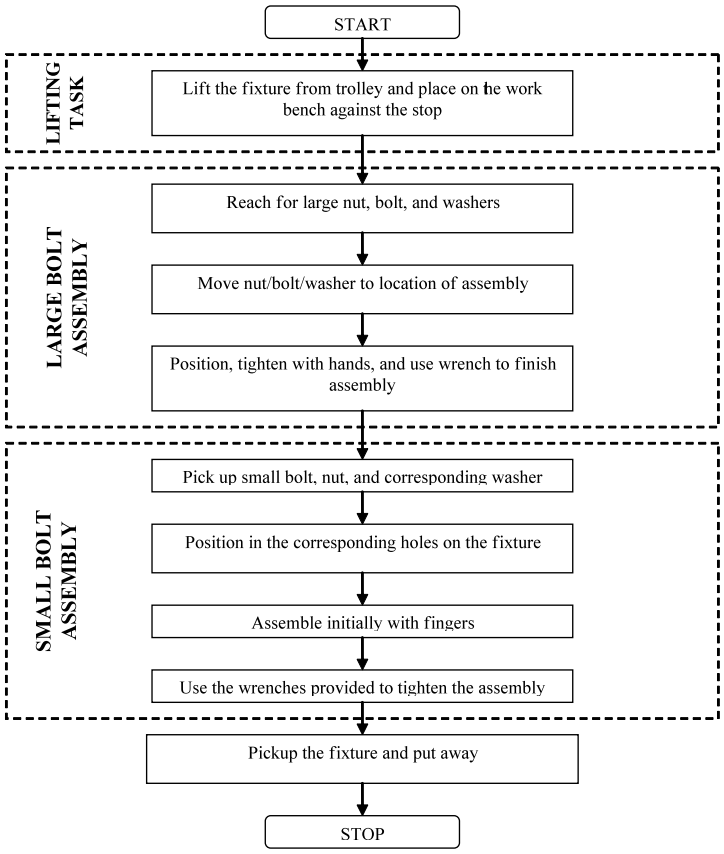

Figure 4. Sequence of operation for the assembly and lifting tasks incorporated in the validation study

3.1 Data Analysis

The sequence of activities shown in Figure 4 was broken down into elements comprising of MTM-1, MTM-2, and materials handling task as shown in Table 9.

Table 9. Elemental breakdown of the task sequence

Task	Description
1	Lift fixture from trolley to work bench
2	Reach to get large bolt
3	Grasp large bolt
4	Move large bolt to fixture location
5	Position in fixture
6	Assemble bolt with hands

Task	Description
7	Reach for large wrench
8	Grasp large wrench
9	Move large wrench to bolt-fixture location
10	Position large wrench to tighten bolt
11	Assemble bolt with tools
12	Move large wrench back to workbench
13	Release large wrench
14	Reach to get small bolt
15	Grasp small bolt
16	Move small bolt to fixture location
17	Position in fixture
18	Tighten with hands
19	Reach for small wrench
20	Grasp small wrench
21	Move small wrench to bolt-fixture location
22	Position small wrench to tighten bolt
23	Assemble bolt with tools
24	Move small wrench back to workbench
25	Release wrench
26	Grasp fixture
27	Move fixture
28	Release fixture

Based on the elements shown in Table 9, time to perform each element was calculated from standard MTM-1 and MTM-2 tables. This time is shown in Table 10 as D00 (time for individuals with no disability based on standard data). Using the multipliers developed for specific tasks from the previous work (Subramanian and Mital, 2009) and the present work, the theoretical times to perform the task with the finger disabilities were calculated. Video recordings were analyzed using the same protocol used in earlier studies. Table 10 shows the estimated times and the observed times for each disability condition.

Table 10. Correction factors for finger disability conditions – comparing calculated and observed

Element	D00	Estimated using multipliers			Observed from video analysis		
		D01	D02	D03	D01	D02	D03
Lift fixture from trolley to work bench	1.004	1.299	1.145	2.401	1.303	1.154	2.393
Reach to get large bolt	0.420	0.424	0.424	0.424	0.424	0.424	0.424
Grasp large bolt	0.088	0.104	0.101	0.130	0.104	0.100	0.129
Move large bolt to fixture location	0.581	0.585	0.585	0.585	0.587	0.591	0.592
Position in fixture	0.272	0.279	0.275	0.292	0.278	0.278	0.299
Assemble bolt with hands	8.224	9.326	8.737	12.457	9.333	8.780	12.485
Reach for large wrench	0.198	0.200	0.200	0.200	0.199	0.200	0.200
Grasp large wrench	0.127	0.283	0.240	0.315	0.290	0.240	0.314
Move large wrench to bolt-fixture location	0.312	0.315	0.315	0.315	0.317	0.316	0.318
Position large wrench to tighten bolt	0.582	0.597	0.589	0.624	0.597	0.599	0.630
Assemble bolt with tools	4.431	4.771	4.830	6.960	4.808	4.846	6.830
Move large wrench back to workbench	0.310	0.313	0.313	0.313	0.313	0.317	0.318
Release large wrench	0.067	0.068	0.068	0.068	0.068	0.068	0.069
Reach to get small bolt	0.851	0.872	0.872	0.872	0.872	0.879	0.870
Grasp small bolt	0.417	0.494	0.474	0.734	0.490	0.471	0.745

Element	D00	Estimated using multipliers			Observed from video analysis		
		D01	D02	D03	D01	D02	D03
Move small bolt to fixture location	0.478	0.491	0.491	0.491	0.493	0.501	0.497
Position in fixture	0.286	0.316	0.300	0.502	0.318	0.298	0.505
Tighten with hands	9.936	13.864	11.450	19.041	14.050	11.382	19.155
Reach for small wrench	0.350	0.359	0.359	0.359	0.362	0.364	0.363
Grasp small wrench	0.236	0.380	0.532	0.437	0.382	0.535	0.436
Move small wrench to bolt-fixture location	0.183	0.185	0.185	0.185	0.183	0.188	0.188
Position small wrench to tighten bolt	0.569	0.630	0.598	1.000	0.637	0.595	1.017
Assemble bolt with tools	6.936	9.167	8.005	14.428	9.014	7.856	14.388
Move small wrench back to workbench	0.183	0.185	0.185	0.185	0.186	0.189	0.188
Release wrench	0.106	0.110	0.110	0.110	0.111	0.112	0.111
Grasp fixture	0.118	0.139	0.136	0.175	0.140	0.136	0.174
Move fixture	0.276	0.278	0.278	0.278	0.276	0.282	0.281
Release fixture	0.113	0.115	0.115	0.115	0.115	0.117	0.118
Cycle Time	42.856	52.017	47.801	70.947	52.118	47.730	71.056

3.2 Results

Table 11 shows the difference between the observed time and estimated time for each element. As seen, the differences range from -1.87% to 2.61% and are statistically insignificant ($\alpha \geq 0.10$). Further, the estimated and observed cycle times were not statistically different from each other ($\alpha \geq 0.10$).

Table 11. Percentage variation of observed time from the estimated time

Element	D01	D02	D03
Lift fixture from trolley to work bench	0.31%	0.79%	-0.33%
Reach to get large bolt	0.00%	0.00%	0.00%
Grasp large bolt	0.00%	-0.99%	-0.77%
Move large bolt to fixture location	0.34%	1.03%	1.20%
Position in fixture	-0.36%	1.09%	2.40%
Assemble bolt with hands	0.08%	0.49%	0.22%
Reach for large wrench	-0.50%	0.00%	0.00%
Grasp large wrench	2.47%	0.00%	-0.32%
Move large wrench to bolt-fixture location	0.63%	0.32%	0.95%
Position large wrench to tighten bolt	0.00%	1.70%	0.96%
Assemble bolt with tools	0.78%	0.33%	-1.87%
Move large wrench back to workbench	0.00%	1.28%	1.60%
Release large wrench	0.00%	0.00%	1.47%
Reach to get small bolt	0.00%	0.80%	-0.23%
Grasp small bolt	-0.81%	-0.63%	1.50%
Move small bolt to fixture location	0.41%	2.04%	1.22%
Position in fixture	0.63%	-0.67%	0.60%
Tighten with hands	1.34%	-0.59%	0.60%
Reach for small wrench	0.84%	1.39%	1.11%
Grasp small wrench	0.53%	0.56%	-0.23%
Move small wrench to bolt-fixture location	-1.08%	1.62%	1.62%
Position small wrench to tighten bolt	1.11%	-0.50%	1.70%
Assemble bolt with tools	-1.67%	-1.86%	-0.28%
Move small wrench back to workbench	0.54%	2.16%	1.62%
Release wrench	0.91%	1.82%	0.91%
Grasp fixture	0.72%	0.00%	-0.57%
Move fixture	-0.72%	1.44%	1.08%
Release fixture	0.00%	1.74%	2.61%
Cycle Time	0.19%	-0.15%	0.15%

4. CONCLUDING REMARKS

The results of the study indicated, as expected, that people with finger disabilities require more time to complete the same activities as compared to people with no finger disabilities. This finding is consistent with the previous findings (Subramanian and Mital, 2009).

Keeping this in mind, the overall objective of this work was to develop multipliers that would allow an accurate estimation of higher level tasks. In this study, we have developed multipliers for that purpose as well as validated those multipliers. It is possible now to accurately estimate the elemental times for MTM-1, MTM-2, and materials handling tasks using these multipliers.

While it has been established that disabilities affect work standards and that the use of multipliers provides an accurate estimation of the cycle time, future studies are still needed to further validate these multipliers. Moreover, the studies need to be broadened to include tasks performed in the service industry.

5. REFERENCES

1. Subramanian, A. and Mital, A. (2009). Developing MTM Multipliers for Finger Disabilities. International Journal of Industrial Engineering, 16(4), 331-343, 2009.

BIOGRAPHICAL SKETCH

Anand Subramanian is a Senior Managing Engineer at JFAssociates, Inc. based in the Washington, DC area. Dr. Subramanian has a Doctoral and Masters Degree in Industrial Engineering from the University of Cincinnati, Ohio. His areas of specialty include time and motion studies, ergonomic evaluations, economic analyses, facilities planning, and warehouse design. He is co-author of a number of national and international journal publications and has made presentations at a number of prestigious Industrial Engineering and Ergonomic conferences.

Anil Mital is a Professor and former Director of Industrial Engineering at the University of Cincinnati. He has a B.E. in Mechanical Engineering with Gold Medal from Allahabad University, India, and an M.S. and Ph.D. in Industrial Engineering from Kansas State University and Texas Tech University, respectively. He is the author/coauthor of over 300 technical publications including 113 journal papers and 13 books. His publications have covered topics such as Human Factors and Ergonomics, Economics Justification, Work Measurement, Metal Cutting, Facilities Design, and Quality Control. Dr. Mital is internationally renowned in the field of industrial engineering and ergonomics. He is the founder editor-in-chief of the International Journal of Industrial Ergonomics and the editor-in-chief of the International Journal of Industrial Engineering.